Towards an Integrated Model of Location Choices, Activity-Travel Behavior, and Dynamic Traffic Patterns

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Abstract

There is increasing interest in the implementation of microsimulation approaches for urban systems modeling. Advances in microsimulation approaches have occurred rather independently in three streams of research - land use modeling, activity-based travel modeling, and dynamic traffic assignment. This paper presents an integrated model system that brings these three streams of research together with a view to capture the interdependencies underlying human decision making and choice behavior in the urban context. The paper offers a detailed overview of the model design and will provide preliminary results from initial test runs of a prototype of the integrated model system.

1. Introduction

Over the past several decades, there has been a clear shift towards microsimulation approaches in modeling urban systems. This shift has generally taken place along three lines of inquiry. First, in the land use modeling arena, attempts are being made to model dynamics in the land use markets. Households transact housing stock, businesses expand/shrink and relocate, and public facilities (schools and parks) get located in space. Land use models are increasingly operating at smaller spatial scales, down to the smallest unit usually represented by the individual parcel or building unit on a parcel. Land use microsimulation models that purport to mimic behavior of location choices include many of the longer-term choices of households and individuals including where to live, where to work and go to school, and whether to participate in the labor force at all. Land use microsimulation models often include a series of household and business market clearing and choice models that provide the basis to determine the longer term choices of households and businesses (Waddell et al, 2007). Second, in the activity-travel demand modeling arena, emerging models simulate the activity-travel patterns of individuals along the continuous time axis while explicitly accounting for time-space prism constraints and interactions, household interactions and task allocation, and modal availability. A synthetic population is generated for the entire region and the activity-based microsimulation model is used to derive activity-travel patterns for each person in the region. The activity-based modeling paradigm recognizes inter-dependencies among trips in a trip chain and destination and mode choices are modeled such that trip chaining constraints are not violated (Kitamura et al, 2005). Third, in the network modeling arena, dynamic traffic assignment models are seeing increasing interest from the planning community. The limitations of the static traffic assignment procedures are now well recognized in the context of emerging policy questions such as managed lanes, dynamic pricing, and real-time information provision to travelers. Dynamic traffic assignment offers the ability to simulate route choices and traffic flows along the continuous time axis while constantly updating paths between origins and destinations (Villalobos et al, 2009).

These three streams of research have largely proceeded in parallel with limited attempts to integrate the model streams into a unifying framework. This is largely due to the complexity of the model systems, the computational and analytical challenges associated with integrating model systems that operate at disparate spatial and temporal scales, and the need for consistent data structures that would facilitate the implementation of iterative feedback loops across model systems. In a multiyear ongoing research project, the authors are developing a unifying model design and paradigm which integrates land use microsimulation models, activity-based microsimulation models of travel demand, and dynamic traffic assignment models. The integrated model paradigm, dubbed SimTRAVEL (Simulator of Travel, Routes, Activities, Vehicles, Emissions, and Land), is intended to serve as a platform that would allow the integrated modeling of urban systems in a seamless fashion.

In this paper, the authors present a comprehensive overview of the design of SimTRAVEL. The paper will include the design considerations that went into the specification of SimTRAVEL, the behavioral paradigms that define the SimTRAVEL approach, and the analytical formulations underlying SimTRAVEL model components. Activity-travel patterns and path choices are modeled along the continuous time axis considering the emergent nature of travel behavior. Accessibility measures that come out of the dynamic traffic assignment affect land use dynamics in the subsequent year, thus reflecting the longer lag period that is often associated with land use changes. The model system will be tested in the Puget Sound (Seattle area in Washington) and Maricopa County (Greater Phoenix) regions of the United States, where some of the individual model systems have already been implemented. In the following section, a brief background of the integrated model system is presented followed by a description of the proposed integrated model design. Section 3 describes some implementation challenges and the last section ends with some concluding thoughts.

2. Model Design

There is growing interest among urban modelers to integrate land use, activity-travel demand, and dynamic traffic assignment models, recognizing the interdependencies that exist among these model entities (Timmermans, 2003; Miller, 2006). Most of the attempts at integrated land use – transport model development have generally focused on two of the three model systems and the integration often involves a loose coupling of the model systems through feedback loops and data exchange processes (Salvini and Miller, 2005). For example, Waddell et al (2008) and Salvini and Miller (2005) have attempted to link a land-use microsimulation model system with an activity-based travel demand model system. Others have tried to integrate activity-travel model systems with dynamic traffic assignment models (e.g., Lin et al, 2008; Lawe et al., 2009; Kitamura et al, 2008; Kitamura et al, 2005; Boyce and Bar-Gera, 2004). However, there have been few attempts at developing a system that integrates all three modeling entities which together represent the urban system – from longer term location choices to medium term vehicle ownership and lifestyle choices to shorter term activity-travel and route choices. This research aims to add to the body of literature on integrated model design by presenting the architecture for an integrated model design that links the three model systems in a robust framework.

This section describes the integrated land use – activity-based travel demand – dynamic traffic assignment model system design dubbed SimTRAVEL (*Sim*ulator of *T*ransport, *R*outes, *A*ctivities, *V*ehicles, *E*missions, and *L*and). The proposed design comprises a generalized framework for integrating three model systems (land use, travel demand and dynamic traffic assignment models) and is not specific to any particular implementations of the model entities.

Two different approaches may be considered for integration of the model systems. The first approach involves a *sequential* application of the model systems. In this approach, the models systems are run independently and sequentially, and then coupled together through feedback loops and input-output data exchange processes. The land use microsimulation model is run first to locate households and businesses to different parcels (or spatial units) in the study region. The activity-based travel demand model is then run through its series of steps with a set of initial network level of service attributes to generate activity-travel patterns for every individual in the population. The activity-travel patterns will then be fed into the dynamic traffic assignment model to route and simulate the trips on the network. The dynamic assignment model would proceed through a series of steps and feedback loops until a stable set of travel times is obtained. This new set of stable travel times will be fed back into the travel demand model which will then generate a new set of activity-travel episodes. This new set of activity-travel episodes will be passed on to the dynamic assignment model to generate yet another set of stable network level of service attributes. This sequential iterative feedback process between the activity-travel model and the dynamic assignment model continues until the network level of service attributes converge. At this point, the converged network level of service attribute set is passed to the land use model to start the simulation for the next year. This sequential application of each independent model system with loose coupling through feedback loops and input-output data flow comprises the *sequential* approach.

Although computationally convenient, the *sequential* approach for integrating the model systems does not adequately represent an individual's trip making behavior. The approach assumes that individuals have a full day schedule planned out in advance based on their knowledge of experienced and expected travel times. However, this notion of having a full schedule of activity-travel engagement planned in advance may not be representative of how behavior emerges over the course of a day. Individuals are temporally and spatially constrained due to time-space constraints, institutional constraints, household constraints, modal constraints, and coupling constraints. In any available period of the day, the activity-travel episode that an individual will pursue, and the attributes of that episode, are influenced by the duration of the open window of opportunity and the network conditions (which define the opportunities that are accessible without violating time-space prism constraints) prevailing at that time. Therefore it is important to incorporate this emergent nature of activity-travel engagement in the model system, and route and simulate trips as they happen.

The proposed alternate design adopts an event-based paradigm in which every activity-travel episode is an *event* that is simulated along a continuous time axis. The land use microsimulation model is run first to simulate the locations of households and businesses. In the activity-based model system, time-space prism constraints are identified based on the scheduling of mandatory activities of the individual as well as of those household members who may be dependent on the individual for transportation. In any unconstrained time period, activities (and travel to the activities) may be undertaken. The choice of mode and destination for any activity is determined using a joint mode/destination choice model. The mode choice set includes only those modes that are available to the individual at the time that an activity is going to be undertaken, and the destination choice set includes only those destinations that can be reached by the fastest mode possible without violating time-space prism constraints. Therefore the joint mode/destination choice model requires an initial set of network level of service attributes to simulate these choices. The set of initial network level of service attributes may be obtained from a validated four-step model or by applying a bootstrapping procedure that will be discussed in detail in the presentation. Assuming that these initial set of network conditions are available, Figure 1 shows the linkage between the activity-travel demand model and the dynamic traffic assignment model.

Assume that the time-resolution of the activity-travel demand model is one minute and that of the dynamic assignment model is six seconds, i.e., the positions of vehicles are updated every six seconds. At the end of every minute, the travel demand model passes information to the dynamic traffic assignment model about all trips that begin during the one minute interval. The trip information includes origin, destination, mode, occupant information, vehicle type and identifier, and trip purpose. The dynamic traffic assignment model receives this information and routes and simulates these trips on the network. Once a trip is completed (i.e., the traveler reaches the intended destination), the arrival information about that traveler is passed back to the activity-travel demand model. Since the travel demand model operates at a temporal resolution of one minute, the dynamic assignment model collects the information about all persons that have reached their destination in a one minute time slice and passes it back to the demand model. The activity-based model system then simulates (the duration of) the specific activity undertaken by the individual. The time allocation to an activity is computed using a duration model, while ensuring that time-space prism constraints are not violated. When an activity is completed, an individual reaches the next decision point on undertaking an activity. The trip information for the next activity is determined in the travel demand model and the set of trips generated in the one minute time interval is passed to the dynamic traffic assignment model. This process is carried out for all 1440 minutes of the day.

In addition to routing and simulating trips, the dynamic assignment model also stores the link travel times at each time-step along the continuous time axis (e.g., in SimTRAVEL, the time-step is one minute). These link travel times are used to update the time dependent shortest paths between origin-destination pairs by time of day for use in the dynamic assignment model, and also to update the travel time by time of day between origin destination pairs for use in the travel demand model. Thus, in each iteration of the integrated demand-supply model system, travel times from the previous iteration are used to route and simulate trips on the network along the continuous time axis. The travel times from the previous iteration serve to represent the "experience" or "expectations" of the traveler regarding travel times between origin-destination pairs. Based on this past experience, the traveler will make choices regarding time of departure, destination, and mode. This information is passed on to the dynamic traffic assignment model which actually routes and simulates the trip on the network. The actual arrival time of the traveler is determined through the network simulation process. Thus, the travel time "experience" of the traveler is updated with each iteration, and this "experience" or travel time information will be used to model travel in the subsequent iteration. In other words, this model design mimics the day-to-day learning process that individuals experience with respect to gaining knowledge about network conditions. Once the travel times show no further change from one iteration to the next, it may be surmised that the system has reached a stable point and the model iterations can be stopped.

Once the demand-supply model interface has reached a stopping point, travel time based accessibility measures are passed to the land use model to represent longer term location choices of individuals and households. There are a number of different formulations for defining accessibility measures that may be used in location choice submodels. Accessibility measurement approaches reported in literature may be broadly classified into proximity-based, gravity-based, isochrone-based, and utility-based (Geurs and van Wee, 2004) approaches. Proximity-based measures are simplistic and may be inadequate for capturing the complexities of real urban environments and human behaviors (Kwan and Weber, 2003). The gravity-based measure assigns an average expected accessibility for all people residing in a zone. Therefore it suffers from the same limitation as proximity-based approaches in that it does not differentiate between residents of a zone in terms of their specific access needs. The isochrones approach is a special case of the gravity-based approach and suffers from limited predictive power in a disaggregate microsimulation modeling context. Similar to the previous two accessibility approaches, the isochrones approach is a generalized measure and may under-estimate the effects of individual-specific accessibility. The utility-based accessibility measure explicitly considers behavioral characteristics of the decision maker. While this approach has the potential to be used as an individual-specific measure of accessibility, it has not been previously applied with success in the context of location choices. Given the limitations of the traditional accessibility measurement approaches, this research effort incorporates a new time-space prism based accessibility measurement for modeling location choices (Miller 1991). The time-space prism based measure derives accessibility at the individual level and reflects opportunities accessible within time-space prisms formed by constraints associated with mandatory activity engagement. Thus, the location choice model components are more tightly connected to the activity-based model components that employ the time-space prism concept to simulate activity-travel patterns of individuals through the course of a day.

3. Challenges

There are numerous challenges associated with the development of an integrated model system of the urban continuum that purports to simulate long term location choices to instantaneous route choices. First and foremost are concerns related to computational tractability and performance. Each model system is a major software enterprise in its own right. To bring these three model systems together in a tightly integrated fashion is undoubtedly going to push the envelope in terms of computational burden and resource requirements. Run times are inevitably going to be extremely long (in the order of several days to a few weeks for standard computer systems) and it is imperative that computational efficiency be considered carefully in the design and programming of the integrated software system.

The three model systems that comprise SimTRAVEL use a host of databases for modeling and simulating location choices and activity-travel patterns. These databases include such entities as census data, travel survey data, network level of service data, land use data, employment data, multimodal network data, and traffic count data (for model calibration and validation). Various components of the model system use the same database, thus calling for the efficient representation and structuring of the data so that duplication is minimized, efficiency in data access and output is maximized, and consistency is maintained. The model systems may operate at different levels of aggregation calling for the ability to aggregate data on the fly as the model chain runs through a simulation. Residential and workplace location choice models in the land use microsimulation model system and destination choice models in the travel model system rely on land use data for making location choice decisions. The flexibility to have these model systems operate at different levels of spatial scale should be maintained in the model design and implementation. Relational database structures have to be developed to ensure that information can be passed seamlessly across model components in the chain.

One of the virtues of moving towards integrated modeling is the potential to capture simultaneity in choice processes and behavioral relationships. One of the limitations of past attempts at sequentially connecting model systems is that such model designs do not allow one to capture or represent simultaneous behavioral relationships that may exist across model systems. For example, consider the notion of residential self-selection in which it is hypothesized that individuals choose residential location choices consistent with their mobility and lifestyle preferences. In other words, residential location choice (which is a component of the land use model) and mode choice to work (an example of a mobility choice) should be modeled in a simultaneous equations relationship. However, mode choice is inevitably included in the activity-travel model system and treats residential location choice variables as exogenous independent variables affecting mode choice. How does one incorporate and recognize residential self-selection effects if these two choice phenomena cannot be linked together in a simultaneous equations framework?

Yet another challenge in the development of an integrated model system such as that depicted in Figure 1 is the need to develop appropriate convergence (stopping) criteria for the looping process. On the network modeling side of the enterprise, one can bring the process to a stop by examining convergence on origin-destination travel times. Once origin-destination travel times do not change from one iteration to the next, the dynamic traffic assignment model has reached stability and the process can be stopped. However, on the demand side (for the activity-travel model), there is no similar stopping criterion. Each run of the activity-travel demand model is one stochastic realization of a random process, thus the activity-travel model will inevitably give a "different answer" or different activity-travel pattern every time it is run. How does the activity-travel "demand" model side of the enterprise come to closure or reach convergence? If the demand model constantly generates activity-travel patterns that are different from one iteration to the next, then the supply model may also never reach convergence because there will be incessant oscillations in travel times between iterations. What type of system can be implemented to ensure that this system comes to convergence or reaches an appropriate stopping point? One possibility is to generate origin-destination matrices at the end of each iteration and then compare these matrices from one iteration to the next to examine convergence on the demand side of the model system. Appropriate averaging techniques can be applied to ensure that convergence is reached efficiently and effectively. Alternatively, one could argue that convergence does not have to be reached on the demand side. It is only necessary to reach convergence in travel times on the supply side, and similar to the real world, demand fluctuates from one day to the next (there is considerable day-to-day variability in travel characteristics) thus eliminating the notion of searching for stability or equilibrium in demand.

While there have been attempts to develop validation criteria for individual model components, there has been limited work in the formulation of validation criteria for an integrated model system as a whole (such as SimTRAVEL). Questions arise as to whether the validation criteria used for individual model components can be translated directly to the integrated model system as a whole. What are appropriate validation criteria for an integrated model system with respect to the ability of the model system to replicate ground conditions. Comparisons against traffic counts and known link travel times offer a strong foundation for validating the network model system. On the demand side, however, the validation criteria are less clear. Time of day distributions of travel, modal splits, and overall measures of demand by market can be examined to ensure that the demand model is replicating aggregate observed patterns of behavior. In addition, however, for the demand side of the model, validation requires the testing of the model to ensure that it is responsive in a behaviorally intuitive fashion to changes in input conditions. Changes in socio-economic characteristics, network conditions, and pricing signals can all bring about changes in activity-travel demand. It is critical to subject the integrated model system to a battery of scenario tests to ensure that the model system is truly "valid".

4. Summary

In this paper, the authors present a comprehensive overview of the integrated land use – activity-based travel demand – dynamic traffic assignment model dubbed SimTRAVEL (*Sim*ulator of *T*ransport, *R*outes *A*ctivities, *V*ehicles, *E*missions, and *L*and). The model is being developed as part of a major ongoing multiyear research effort. The design of the integrated model has been completed and software prototype development is well underway. The two regions that are being considered for SimTRAVEL prototype testing are Puget Sound and Maricopa, where individual model components have already been applied to varying degrees. Over the next few months, the research team will be completing the development of early prototypes and subjecting the early versions to extensive testing to check the software architecture, assess computational performance, and optimize database structures and information flow handling processes.

The integrated model design presented in this paper incorporates some appealing features. The arrival times are determined by conditions on the network and are simulated in real time and not based on any predetermined travel times. The time-dependent shortest paths that feed as input into the dynamic assignment model are defined in a way that mimics the day-to-day learning process of individuals whereby the shortest paths get updated based on traveler experience. Consistent with the notion of dynamic traffic assignment, shortest paths are time-dependent shortest paths. This means that the shortest paths are based on experienced travel times and recognizes the fact that time elapses when one moves from one link to the next along a route. The model design also considers a time-space prism based approach for measuring individual-specific transportation/land use accessibility which is suited to a microsimulation modeling environment.

In the presentation, the authors will present the model design in detail. Then, the authors will present the numerous challenges as outlined in this paper and offer solutions to each of these challenges and describe how these solutions were implemented in the context of the development of SimTRAVEL. The authors will then present the software system prototype, discuss early tests of the system, and present results from the early tests of the prototype. These results will clearly show various aspects of the model system in terms of computational performance, data needs, convergence criteria, ability to replicate ground conditions, and responsiveness to changes in input conditions. The authors will offer a detailed discussion on the lessons learned in the integration of land use, activity-travel demand, and dynamic traffic assignment models. The presentation will include descriptions of the software programs, code, data structures, and interfaces that are being developed in an open-source environment for free use by the user community.

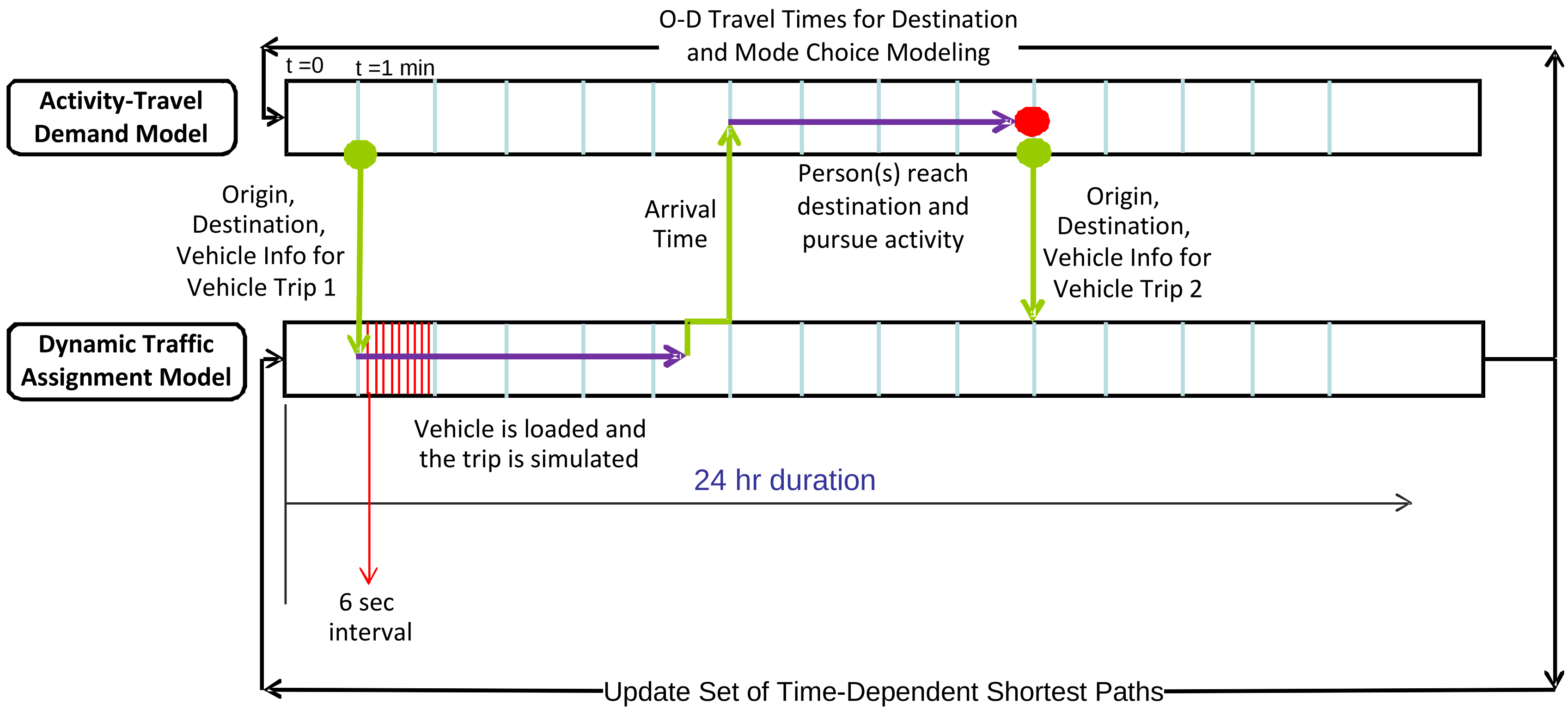

Figure 1. Integrated model design showing linkage between the activity-travel demand model and the dynamic assignment model

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